NUMERICAL MODELING OF POSSIBLE STRIKE-SLIP FAULTING IN LAVINIA PLANITIA, VENUS.

Elissa Koenig and Atilla Aydin, Department of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305-2115

Introduction

Tectonic deformation of the lithosphere on Venus may result from horizontal stresses induced by mantle convection (1,2,3). Lowland areas on Venus which correspond to mantle downwellings may experience horizontal compressive stresses (3,4,5). This is consistent with many of the structural features observed in lowland volcanic plains, such as contractional ridge (fold) belts (6) and wrinkle ridges formed in association with shallow thrust faults (7,8). However, high resolution radar images from the Magellan mission to Venus revealed for the first time the presence of fracture belts and extensional lineaments (grooves) in the lowland volcanic plains of Lavinia Planitia (9,10). Though the existence of contractional features was known and studied prior to the Magellan mission, lowland extensional features were a new discovery and the mechanisms responsible for their formation remain unclear.

We address the origin of a system of extensional lineaments in the southwest region of Lavinia Planitia. We believe these features are secondary structures formed in association with localized strike-slip faulting over hundreds of kilometers, and we use two-dimensional boundary element techniques to assess the feasibility of this mechanism.

Lavinia Planitia

Lavinia Planitia is located in the southern hemisphere of Venus, spanning from about 35°S to 54°S and 327°E to 359°E. This area includes a high concentration of ridge and fracture belts, both of which are zones of deformation that rise hundreds of meters above the surrounding plains. The primary feature in the southern half of Lavinia Planitia is a deformation belt known as Molpadia Linea. Extensional lineaments are common to the area northwest of the belt and are found over a distance of nearly 700 km along its length. These lineaments have been interpreted as normal faults and grabens; we use the general term fracture to describe their extensional origin.

Fractures are localized in two areas along Molpadia Linea. They appear to emanate from the terminations of ridges within the deformation belt and curve smoothly into the surrounding plains. Numerous short fracture segments near the belt indicate the fracture array initiated there and propagated away from Molpadia Linea, resulting in a set of longer, more widely spaced fractures due to stress shadowing effects.

Fracture formation model

The observed fracture geometries are similar to the patterns of joints and normal faults formed as secondary structures of strike-slip faulting. Strike-slip motion along a fault results in quadrants of tensile and compressive mean normal stresses around the plane of the fault (11,12). If the center of the fault is chosen as the origin of a local coordinate system (with the fault parallel to the x-axis), then for right-lateral slip the average stress is compressive in the first and third quadrants, and tensile in the second and fourth. Slip along the fault may cause formation of secondary structures, such as joints, veins, tail cracks and normal faults in the tensile quadrant, and solution surfaces, folds, and thrust faults in the compressive quadrants. Secondary fractures tend to be localized in regions of high stress concentrations and large slip gradients around fault tips.

Based on the spatial and temporal relationships determined from our structural mapping, we believe that the observed fracture system in Lavinia Planitia formed as the result of right-lateral slip localized along Molpadia Linea, which acted as a pre-existing weak zone hundreds of kilometers long.

Numerical modeling

The mechanics of strike-slip faulting are investigated using boundary element method techniques to analyze the factors which promote shear failure along a fault plane and subsequent deformation of the surrounding region. The displacement discontinuity method of Crouch and Starfield (13) has been adapted to incorporate fracture growth (14) as well as the effects of friction and inelastic slip on a fault plane (15). A fault is idealized as a crack-like (zero thickness) interface with behavior dictated by the specification of four mechanical properties: shear stiffness K_s, normal stiffness K_n, cohesion C_0, and coefficient of friction μ. Shear failure is predicted if the shear stress, σ_s, along the plane exceeds the resistive effects of cohesion, friction, and normal stress, σ_n, according to the Mohr-Coulomb criterion:

$$|\sigma_s| \geq C_0 - \mu\sigma_n$$

In this study we idealize Molpadia Linea as a fault subject to remote loading and investigate the effects that varying remote stresses and friction have on the slip gradient along the fault, the stress field around the fault, and the predicted orientation of secondary fractures.

We fix the orientation of the applied remote stresses with respect to the fault plane by considering the orientation of fractures away from the deformation belt. As secondary fractures propagate away from the parent fault they will orient themselves parallel to the direction of maximum remote compression (11). Therefore, the angle between the secondary fracture sets and the deformation belt in Lavinia Planitia (approximately 75° counterclockwise from the belt axis) is used to estimate the direction of maximum compressive stress with respect to the fault plane.

With the orientation of the fault plane given, we set the cohesion along the fault plane to zero, and use the Mohr-Coulomb criterion to calculate the maximum value of friction along the fault that will allow slip. Taking the case of uniaxial compression, we maximize the shear stress on the plane while minimizing the confining normal stresses. This provides the upper limit to the value of friction that will allow slip on a plane of a given orientation. For the geometry of Molpadia Linea, no slip will occur if the friction coefficient μ is greater than 0.27. This implies Molpadia Linea acts as a very weak fault. This upper bound on the coefficient of friction decreases with increasing normal stresses acting on the fault plane. We use this information to guide our numerical analyses.

Preliminary models show the development of regions of reduced mean normal stresses around the fault plane relative to the regional values of mean normal stress. These areas are where fracture initiation and growth are most favorable. The angle of secondary fracture formation varies with friction values; the lower the friction, the higher the take-off angle of the fracture (measured counterclockwise away from the fault axis).

The boundary element technique used here is a powerful tool which will allow us to analyze the stress distributions and fracture geometries around the Molpadia Linea under various remote loading conditions and for different values of friction. These results will be compared to the observed structures in Lavinia Planitia to test the validity of the strike-slip faulting hypothesis. The results of this research will be interesting for a number of reasons: 1) shear on Venus usually occurs over broad regions (9,16), so this may be a rare example of localized large-scale strike-slip faulting in Venus, 2) the model provides a mechanism for the formation of extensional features in what is generally believed to be a contractional tectonic setting (i.e., a lowland basin), and 3) the remote loading conditions and lithospheric properties required to generate the observed structures may be compared to other estimates of tectonic stresses and lithospheric properties based on investigations of mantle convection dynamics.

References. (1) Phillips, 1986, *GRL*, *13*, 1141. (2) Basilevsky et al., 1986, *JGR*, *91*, 399. (3) Zuber, 1990, *GRL*, *17* 1369. (4) Phillips et al., 1991, *Science*, *252*, 651. (5) Bindschadler, et al., 1992, *JGR*, *97*, 13495. (6) Zuber, 1987, *JGR*, *92*, 541. (7) Plescia and Golombek, 1986, *GSA Bull*, *97*, 1289. (8) Watters, 1991, *JGR*, *96*, 15599. (9) Solomon, et al, 1991, *Science*, *252*, 297. (10) Squyres, et al., 1992, *JGR*, *97*, 13579. (11) Erdogan and Sih, 1963, *J. Basic Eng*, *85*, 519. (12) Pollard and Segall, 1987, in *Fracture Mechanics of Rock*, ed. Atkinson, Academic (London). (13) Crouch and Starfield, 1990, *Boundary Element Methods in Solid Mechanics*, Unwin Hyman (Boston). (14) Thomas and Pollard, 1993, *JSG*, *15*, 323. (15) Cooke and Pollard, in press, *JGR* (16) Solomon, et al, 1992, *JGR*, *97*, 13199.